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RESEARCH MEMORANDUM

EFFECT OF CURRENT DESIGN TRENDS ON AIRPLANE SPINS AND RECOVERIES

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Design of airplanes for transonic and supersonic flight has had pronounced effects upon the vertical-tail design requirements and upon the control manipulation required for satisfactory recovery from a spin, and also upon the nature of the spinning motion. One of the most important influences of current design trends, such as placing jet and rocket engines in the fuselage, utilizing thin swept wings, and using long-nosed fuselages, has been to alter greatly the mass distribution of the airplane. Figure 1 illustrates the trend in airplane mass distribution. The abscissa indicates the amount of mass placed along the wings of the airplane, whereas the ordinate indicates the amount of mass placed along the fuselage. The corresponding dependent variable plotted diagonally $\frac{I_X - I_Y}{mb^2}$ indicates the relative distribution of mass along the wings and fuselage. The two designs shown in the lower right part of the figure represent World War II airplanes, whereas those in the upper left part are examples of a current fighter and of a research type of airplane. It can be seen that the trend is toward large negative values of $\frac{I_X - I_Y}{mb^2}$, indicating that airplanes are becoming very heavily loaded along the fuselage.

In order to obtain information regarding vertical-tail design requirements through a wide range of mass distribution common to present swept-wing high-speed fighter and research airplanes, an investigation was conducted for various tail configurations on a design having 35° of wing sweep. Figure 2 is considered preliminary, but is an indication of the control requirements for satisfactory recovery through a wide range of mass distribution. The abscissa $\frac{I_X - I_Y}{mb^2}$ indicates the relative distribution of mass along the wings and fuselage, large negative values indicating a concentration of mass along the fuselage. The ordinate TDPF (tail-damping power factor) may be considered an indication of the effectiveness of the vertical tail in providing anti-spin aerodynamic yawing moment for recovery. It is defined in reference 1 in terms of the unshielded fixed and movable vertical-tail areas and their respective distances from the airplane center of gravity. The curves indicate the minimum value of TDPF required at a given mass distribution for satisfactory recovery by various control manipulations.

For example, a design having a value of TDPF below the curve will not recover satisfactorily by rudder reversal, a value above the curve being required. The small separate part of the curve at the extreme right of the chart represents the complete mass-distribution range for practically all airplanes up to and including World War II designs and some designs of the late 1940's. The vertical-tail design requirements for satisfactory recovery by rudder reversal are indicated. Also, when large items of mass are placed in the wings of the airplane $\left(\text{small negative or positive values of } \frac{I_X - I_Y}{mb^2}\right)$ the rudder loses effectiveness but downward movement of the elevators becomes effective and generally necessary to assist the rudder in satisfactorily terminating the spin.

The range of mass distribution of fighter and research airplanes of the past few years is represented by the complete chart (fig. 2). The bands used to separate the boundaries indicate that future additional research will probably more definitely establish these boundaries. The requirements for satisfactory recovery from the spin by rudder reversal (which may also be considered as the requirements by both rudder and elevator) become more severe as the percentage of mass along the fuselage is increased. It can be seen that the effectiveness of the rudder decreases rapidly in the region of $\frac{I_X - I_Y}{mb^2} = -250 \times 10^{-4}$. Further increase in mass along the fuselage produces a region in which spins can not be obtained; still further increase gives a mass region for which spins will again be obtainable and it may be difficult to obtain satisfactory recovery by rudder reversal or by rudder and elevator movements. Movement of the ailerons with the spin (stick right in a right spin) in conjunction with rudder reversal, however, leads to satisfactory recoveries. It thus appears that for present high-speed airplanes with mass distributed chiefly along the fuselage, the rudder may need assistance for recovery by movement of the ailerons with the spin, thus indicating the importance of aileron effectiveness at spinning attitudes. In order to obtain recovery by rudder action alone, very large values of TDPF may be required which may unduly penalize the design. For earlier designs, rudder throw available was usually $\pm 30^\circ$. Present-day airplanes generally have less rudder throw ($\pm 20^\circ$) which may also contribute to the decrease in the effectiveness of the rudder for spin recovery and probably accounts for the difference in TDPF requirements indicated at $\frac{I_X - I_Y}{mb^2} \approx -200 \times 10^{-4}$.

Experience indicates that for current designs, the importance of rudder and elevator as the primary controls for termination of the spin is decreasing with a corresponding increase in the prominence of ailerons as the important control for recovery. Use of ailerons with the spin when $\frac{I_X - I_Y}{mb^2}$ is highly negative greatly decreases the pro-spin inertia yawing moment. For current designs decreasing the pro-spin inertia yawing moment can be accomplished more readily than can provision of sufficient aerodynamic yawing moment by rudder design.

Another result of the increased percentage of mass along the fuselage is a decided change in the nature of the spin. The familiar steady spin at a fairly constant angle of attack, generally within the range of 30° to 60°, is becoming less common and in its place a cyclic oscillatory spin, consisting primarily of rolling and yawing oscillations, is being obtained. Reference 2, based on tests of unswept-wing designs, showed that, when the mass was distributed chiefly along the fuselage, large nose lengths were conducive of very oscillatory spins. Figure 3 shows the separation of regions of steady and oscillatory spins for both unswept- and swept-wing designs. Increasing negative values along the abscissa indicate increased percentage of mass along the fuselage; whereas increasing values of the ordinate, side-area moment factor, indicate large nose lengths. Side-area moment factor is defined as the ratio of the moment of the projected side area ahead of to that behind the airplane center of gravity. The separation of steady and oscillatory spins previously obtained for unswept-wing models is indicated in the right-hand part of the figure. A preliminary analysis based on tests of several models having wing sweep ranging from 35° to 45° indicates a similar trend toward oscillatory spins, but it also indicates that, for very extreme distribution of mass along the fuselage, there may be a reoccurring tendency toward less oscillatory spins.

For both unswept-wing and swept-wing designs, the oscillations may cause the airplane to stop spinning with no control movement, and it may even be difficult to obtain a spin. It was previously indicated for several specific unswept-wing designs that when the spin was very oscillatory, vertical-tail design requirements for spin recovery would be very moderate and that even rudder area above the horizontal tail would be effective in terminating the spin. For the swept-wing versions, however, it appears that recovery from any oscillatory spin obtained may sometimes be difficult unless very large values of TDPF are available, or unless ailerons are deflected with the spin.

Results have indicated that when aileron deflection with the spin is required for recovery, upper-surface spoilers will not afford a satisfactory substitute, apparently because at the high angles of attack of the spin, they are ineffective. Lower-surface spoilers, located on the inboard portion of the wing, will also generally be much less effective than ailerons. Use of ailerons on delta wings, either conventional or half-delta, will generally be effective for termination of the spin. Extended leading-edge slats will generally expedite recovery for current airplanes which have mass distributions chiefly along the fuselage. Research is currently being conducted to determine the aerodynamic effects of wing sweep and to more clearly isolate the factors which affect the spin and recovery through the wide range of mass and dimensional characteristics common to current and proposed designs.

In summation, it may be said that, as a result of current design trends, it appears that provision of a rolling moment in the direction of the turning rotation will be very effective, and may be necessary, for termination of any spin obtained. The steady spin is being eliminated and is being replaced by a cyclic large-motion oscillation. In many instances, it may be difficult to obtain spins on the airplane, but those that are obtained may be difficult to terminate unless ailerons are deflected with the spin. Research to date seems to indicate that wing sweep, use of heavy jet and rocket engines in the fuselage, and long fuselage nose lengths are the primary causes of the changes in the nature of the spin and in the requirements for recovery.

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2. Stone, Ralph W., Jr., and Klinar, Walter J.: The Influence of Very Heavy Fuselage Mass Loadings and Long Nose Lenths upon Oscillations in the Spin. NACA TN 1510, 1948.

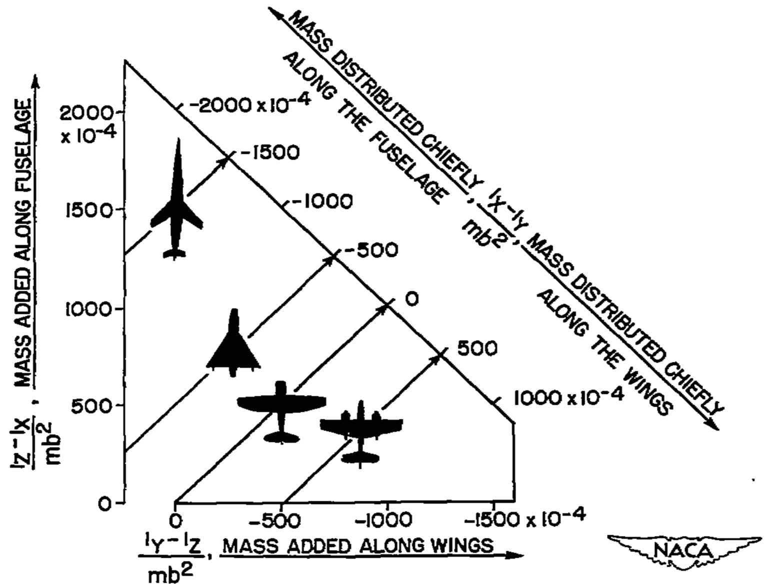

Figure 1.- Influence of airplane design on mass distribution.

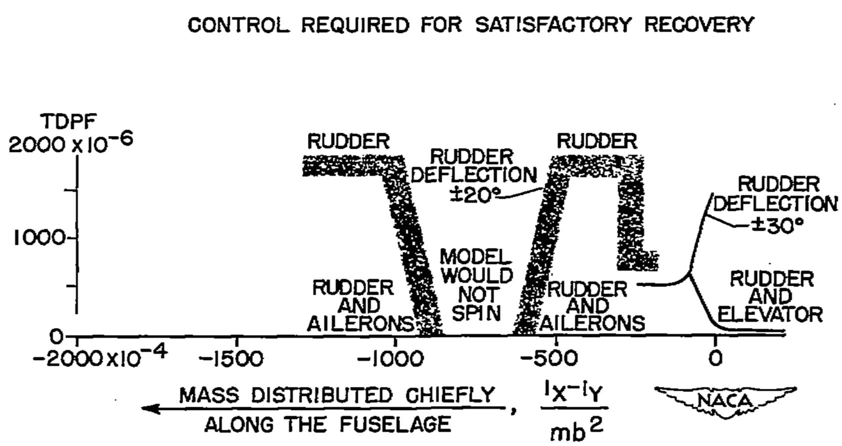

Figure 2.- Vertical-tail requirements for satisfactory recovery by various control manipulations through a wide range of mass distribution.

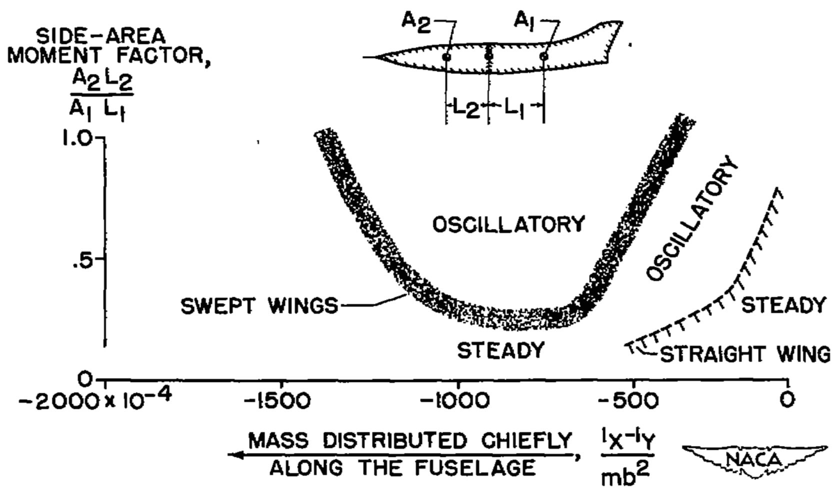

Figure 3.- Influence of mass distribution and nose length (side-area moment factor) upon nature of spin.

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